EFFECT OF LOW FREQUENCY EXCITATION LOCATION FOR CRACK DETECTION IN ALUMINIUM PLATE USING NONLINEAR VIBRO-ACOUSTIC METHOD

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MASTER OF SCIENCE IN MECHANICAL ENGINEERING

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DECLARATION

I declare that this thesis entitled “Effect of Low Frequency Excitation Location for Crack Detection in Aluminium Plate Using Nonlinear Vibro-Acoustic Method” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : .....

Name : Tino Hermanto

Date : .....

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Mechanical Engineering.

Signature	:	…….....
Supervisor Name	:	Dr. Abd Rahman Bin Dullah
Date	:	……

DEDICATION

To my loving parents and family

ABSTRACT

Fatigue crack occurs due to the material failure to withstand the load when applied repeatedly. Nonlinear vibro-acoustic is a highly reliable and sensitive method for damage detection. Vibro-acoustics method (VAM) is a method based on the fact that a high frequency ultrasonic wave propagates in the testing structure is modulated by the low frequency excitation. Besides that, the interaction between a high frequency vibration and a low frequency vibration results in nonlinear acoustic wave modulation. Low frequency excitation is a crucial element of nonlinear acoustic technique when used for crack detection. It is important to know what frequencies and level of excitation required to fully open cracks and where to excite the structure in order to maximize the detectability of the crack. The purpose of this research are to determine the optimized excitation location and investigate the effect of the first three vibration mode shapes natural frequencies on crack detection in cracked aluminium Al-2024 plate specimen by using VAM techniques.
Micro-crack was created on aluminium plate by using Electro Discharge Machine (EDM) and fatigue test. The plate was hung with cords to provide free boundary condition. A mechanical shaker by a TIRA GmbH type S 50018 is attached at bottom corner of the plate and suspended by soft string. The piezoelectric transducer were used to provide simultaneous interaction between low frequency excitation and high frequency inputs respectively. Three middle cracked plate were excited with first, second and third mode frequency excitation at excitations 21 positions for modal analysis. The experimental modal analysis carried out were validated by finite element model simulation. The surface deflection above the crack are measured by Optomet SWIR scanning laser Doppler vibrometer in time domain signal are converted into frequency signal by using MATLAB software. Surface deflections was used to determine the most effective frequency mode and excitation location. The amplitude modulation intensity, *R*-values were used to determine the effectiveness of the frequency to predict the crack location in the aluminium plate. The results show the surface deflection and *R*-value are highest at the bottom corner of the plate. These shows that the most effective locations for excitation is at the edge of plate (location 15) and first vibration mode frequency produces the most significant effect on crack detection. Thus the selection of vibration mode frequency and excitation location are important in nonlinear vibro-acoustic defect detection technique.

KESAN LOKASI PENGUJAAN FREKUENSI RENDAH TERHADAP PENGESANAN RETAK PADA PLAT ALUMINIUM MENGGUNAKAN KAEDAH VIBRO-AKUSTIK TAK LINEAR

ABSTRAK

Retakan lesu boleh terjadi akibat kegagalan bahan untuk bertahan apabila beban digunakan berulang kali. Alat vibro-akustik tak linear adalah kaedah yang sangat dipercayai dan sensitif untuk mengesan kecacatan. Kaedah Vibro-akustik (VAM) adalah satu kaedah berdasarkan hakikat bahawa gelombang ultrasonik yang berkelajuan tinggi menyebar dalam struktur ujian dimodulasi oleh pengujaan frekuensi rendah. Selain itu, interaksi antara getaran frekuensi tinggi dan getaran frekuensi rendah menghasilkan modulasi gelombang akustik bukan linear. Pengujaan frekuensi rendah adalah elemen penting dalam teknik akustik bukan linear apabila digunakan untuk pengesanan retak. Adalah penting untuk mengetahui kekerapan dan tahap pengujaan yang diperlukan untuk membuka retak sepenuhnya, lokasi untuk merangsang struktur untuk memaksimumkan kesan ini dan kesan retakan pada frekuensi semula jadi. Tujuan penyelidikan ini adalah untuk menyiasat kesan pengujaan tiga frekuensi rendah yang berbeza pada spesimen plat Al-2024 aluminium retak pusat dengan menggunakan teknik VAM. Retakan ini dihasilkan dengan menggunakan Electro Discharge Machine (EDM) dan ujian lesu. Plat telah digantung dengan tali untuk menyediakan keadaan sempadan bebas. Sebuah penggoncang mekanikal oleh TIRA GmbH jenis S 50018 dipasang di sudut bawah plat dan digantung oleh tali lembut. Transduser piezoelektrik digunakan untuk menyediakan interaksi serentak antara pengujaan frekuensi rendah dan input frekuensi tinggi masing-masing pada 21 lokasi. Analisis modal secara ujikaji ini disahkan oleh simulasi model unsur terhingga. Pesongan permukaan diukur menggunakan vibrometer Doppler laser pengimbasan Optomet SWIR dalam domain masa dan ditukarkan ke domain frekuensi dengan menggunakan perisian MATLAB. Pesongan permukaan dan nilai R digunakan untuk menentukan mod frekuensi dan lokasi pengujaan yang paling berkesan. Keputusan ujikaji menunjukkan bahawa pesongan permukaan and nilai R adalah paling tinggi pada hujung bawah plat. Ini menunjukkan bahawa lokasi yang paling berkesan untuk pengujaan berada di tepi plat (lokasi 15) dan *mod frequensi getaran pertama menunjukkan kesan yang ketara pada pengesanan retak. Jadi, pemilihan mod frequensi getaran dan lokasi pengujaan adalah penting dalam pengesanan retak lesu kecil pada plat aluminium menggunakan teknik vibro-akustik tak linear.*

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Love you all

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LIST OF ABBREVIATIONS

DI	-	Damage Index
DOF	-	Degrees of Freedom
EDM	-	Electronic Discharge Machine
FEA	-	Finite Element Analysis
FFT	-	Fast Fourier Transform
FRF	-	Frequency Response Function
HF	-	High Frequency
IM	-	Impact Modulation
LF	-	Low Frequency
MAA	-	Military Aviation Authority
NASA	-	National Aeronautics and Space Administration's
NDT	-	Non-destructive Testing
NWMS	-	Nonlinear Wave Modulation Spectroscopy
PZT	-	Peizoelectric Transducer
SHM	-	Structure Health Monitoring
SLDV	-	Scanning Laser Doppler Vibrometer
UTM	-	Universal Testing Machine
VAM	-	Vibro-Acoustic Modulation

LIST OF SYMBOLS

	-	Parameter That Depends on The Immersion Oscillator
A_0	-	High Frequency Amplitude
A_1	-	Sideband Amplitude
A_2	-	Sideband Amplitude
Am	-	Vibration Amplitude
An	-	Ultrasonic Wave Amplitude
I	-	When the System is Driven by a Frequency
m	-	Integer Indicating The Number of Ultrasonic Wave
n	-	Number of Vibration Modes
P_{xx}	-	Power Spectral Density
P_{yx}	-	Cross Power Spectral Density
Q	-	Factor Which is Used to Get an Echo
R	-	Parameter of *R*-Value
T_{xy}	-	Estimated Function
Ω	-	Intensity of Oscillations

LIST OF PUBLICATIONS

JOURNAL

1 Hermanto, T., Jenal, R.B., Dullah, A.R., Putra, A., Salim, M.N., 2018. Effect of low frequency excitation for crack detection using nonlinear vibro-acoustic modulation method. *Science & Technology Research Institute for Defence (STRIDE)*, 11(2), pp. 277-286.

2 Hermanto, T., Dullah, A.R., Jenal, R.B., Salim, M.N., 2017. Stress determination by using out-of-plane deflection with scanning laser doppler. *Science & Technology Research Institute for Defence (STRIDE)*., 10(1), pp. 51-61.

CHAPTER 1

INTRODUCTION

1.1 Introduction

This thesis entitled ‘Effect of Low Frequency Excitation for Crack Detection in Aluminium Plate using Nonlinear Vibro-Acoustic Method’ presents the introduction covered on this research study. This chapter gives a brief overview of background, problem statement, objectives scopes, and thesis outline that involves in this study.

1.2 Background of study

The process of implementing and characterization of damage strategy for aerospace, civil, and mechanical engineering structures such as bridges, ships, pipelines, and aircrafts is referred to as Structural Health Monitoring (SHM). Improvements in component design are mostly related to weight reduction, but by analysing data collected by SHM systems, other properties of the structure can be optimised as well. Structural damage can continue to grow for a long time, but the final failure is usually a sudden event and the consequences can be catastrophic such as an aircraft crash and collapse of a structure. Such disasters can be predicted and ultimately avoiding such events is an important motivation for SHM. Some application of SHM that are widely used is depicted in Figure 1.1.

(a) Aircraft structure inspection

(b) Bridge inspection

Figure 1.1: An overview of potential application fields for SHM techniques

The development of SHM for aerospace applications has continued and increased considerably in technical sophistication with current applications being investigated for commercial and military aircraft, the National Aeronautics and Space Administration's (NASA) space station and the next generation of reusable launch vehicles.

One unique aspect of aerospace SHM applications is that regulatory agencies have been involved with the certification of systems that are deployed on rotorcraft. Every 2 years, a bridge will undergo a visual inspection for damage. Damage in the bridge such as cracking or corrosion could affect their performance, thus there are some bridges that were equipped with acoustic emission sensor to detect the crack growth. It is important to detect the crack or damage at early stage to avoid the accident.

The major difference between a traditional NDT (Non Destructive Test) and SHM system lies mainly in the integrated system approach and autonomous inspection, which is confirmed by the latter results in the development of intelligent structures. A number of NDT techniques have been successfully implemented into SHM applications.

In the following, detailed of different NDT technique, such as visual inspection is inspection of the components by human eye. This is the oldest and most used NDT technique. It requires that the monitored component is accessible and clean. The sensitivity of visual inspection is limited to surface damage. During-operation, monitoring is often impossible. Ultrasonic NDT methods are based on the interaction of ultrasonic acoustic waves with defects. Ultrasonic waves experience mode conversion when they enter a region with different acoustic impedance, as in the case of a defect reported by Castaings et al. (2002).